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INTEGRATED PIEZOELECTRIC ENERGY HARVESTING: AUTOMATING TOLL COLLECTION AND HIGHWAY STREET LIGHTS

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ABSTRACT

This research paper presents a comprehensive study on the integration of piezoelectric energy harvesting technology for the dual purpose of automatic toll collection and highway street lighting. The project proposes a novel system architecture that leverages the piezoelectric effect to convert mechanical stress from passing vehicles into electrical energy, thereby powering both toll collection mechanisms and street lights. The system incorporates RFID technology for seamless vehicle identification and toll deduction, along with an intelligent control system for efficient energy management. The paper discusses the design, implementation, advantages, challenges, and considerations of the proposed system, highlighting its potential for sustainable infrastructure development and energy efficiency.

KEYWORDS: Piezoelectric Energy Harvesting, Automatic Toll Collection, Highway Street Lighting, RFID Technology, Renewable Energy, Sustainable Infrastructure

1. INTRODUCTION

The integration of renewable energy sources into transportation infrastructure has garnered significant attention in recent years as part of efforts to promote sustainability and energy efficiency. One promising avenue in this domain is the utilization of piezoelectric energy harvesting technology for powering essential components of transportation systems, such as toll collection facilities and street lighting along highways. This research paper explores the design, implementation, and implications of an integrated system that harnesses the piezoelectric effect to generate electricity from the mechanical stress exerted by passing vehicles on toll roads.

Traditional toll collection systems rely on grid power, posing challenges in terms of energy consumption, cost, and environmental impact. Similarly, highway street lighting often relies on conventional power sources, contributing to energy inefficiency and carbon emissions. By leveraging the piezoelectric effect, which enables the conversion of mechanical pressure into electrical energy, this research endeavors to address these challenges by proposing a self-powered solution for toll collection and street lights. The proposed system integrates piezoelectric discs embedded in the toll road surface to capture the mechanical energy generated by passing vehicles. This harvested energy is then utilized to power RFID-based automatic toll collection mechanisms and control the operation of highway street lights. RFID technology enables seamless vehicle identification and toll deduction, while an intelligent control system optimizes energy utilization and ensures efficient operation of the infrastructure.

This paper provides a comprehensive examination of the project methodology, encompassing the underlying principles of the piezoelectric effect, the implementation of RFID technology, and the detailed architecture of the integrated system. Furthermore, it explores the advantages, challenges, and considerations associated with the deployment of such a system, emphasizing its potential to promote sustainability, reduce reliance on grid power, and enhance the efficiency of transportation infrastructure.

By presenting a novel approach to toll collection and street lighting through the integration of renewable energy sources, this research contributes to the discourse on sustainable transportation systems and lays the foundation for future innovations in infrastructure development. Through empirical analysis and theoretical insights, this paper seeks to elucidate the transformative potential of piezoelectric energy harvesting in shaping the future of transportation infrastructure towards a more sustainable and energy-efficient paradigm.

2. MATERIALS AND METHODS:

2.1. Proposed System

The proposed system integrates piezoelectric energy harvesting technology with RFID-based toll collection and street lighting control mechanisms. Piezoelectric discs, embedded in the toll road surface, serve as the primary energy harvesting component. When vehicles pass over these discs, the mechanical pressure applied generates electric charges through the piezoelectric effect. These charges are then converted into usable electrical energy through bridge rectifiers and stored in a 12V battery for later use.

The system's control and automation are facilitated by an Arduino Uno microcontroller, powered by the harvested energy from the battery. The Arduino interacts with various components, including RFID readers for vehicle identification and toll deduction, and a light-dependent resistor (LDR) sensor

for ambient light detection.

During toll collection, RFID tags installed on vehicles are identified by RFID readers as they approach toll gates. The Arduino communicates with a central database to verify vehicle information and deduct toll fees automatically from linked accounts. A servo motor controlled by the Arduino operates the toll gate barrier, allowing authorized vehicles to pass seamlessly.

For street lighting control, the LDR sensor detects ambient light levels, and the Arduino adjusts the on/off function of the street lights accordingly. During low-light conditions, the Arduino activates the street lights, utilizing the stored energy from the battery.

This integrated system architecture optimizes energy harvesting, ensures efficient toll collection processes, and enhances street lighting management, all while promoting sustainability and reducing dependence on external power sources.

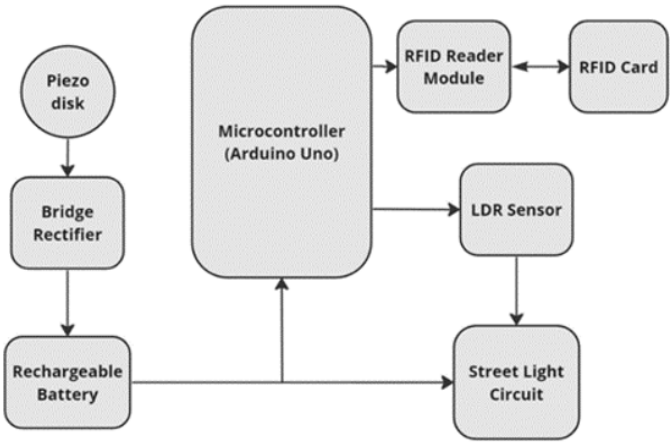

Figure 1. Block diagram

2.2. Methodology

2.2.1. Piezoelectric Effect

The piezoelectric effect involves certain materials generating an electric charge when subjected to mechanical stress. In the context of toll collection and street lighting, piezoelectric discs embedded in the road surface deform under the weight of passing vehicles, generating electric charges. This mechanical-to-electrical energy conversion is harnessed through specialized circuits, converting the generated alternating current (AC) into direct current (DC) for storage and use. The harvested energy can power toll collection systems and street lights, reducing reliance on grid power and promoting sustainability. This innovative approach taps into renewable energy sources, offering cost savings and environmental benefits while increasing energy efficiency in transportation infrastructure. By utilizing the piezoelectric effect, infrastructure can be powered by the very vehicles it serves, representing a promising advancement in sustainable energy solutions for transportation systems.

2.2.2. RFID Technology:

RFID (Radio Frequency Identification) technology enables automatic vehicle identification and toll deduction through electromagnetic fields. RFID tags, affixed to vehicles, contain unique identifiers and antennas. As a vehicle approaches a toll gate, an RFID reader emits radio waves, powering the tag and reading its data. This information, including the vehicle's identity and toll fee, is transmitted to a central database for verification. The database communicates back to the toll gate system, authorizing the deduction of the predetermined toll amount from the vehicle owner's account linked to the RFID tag. This seamless process eliminates the need for manual toll collection, enhancing efficiency and reducing congestion. The integration of RFID technology streamlines toll operations, ensuring accurate and timely transactions. Moreover, it provides a secure and convenient method of toll payment for drivers while enabling transportation authorities to manage tolling systems effectively. Overall, RFID technology plays a crucial role in modernizing toll collection processes, offering a reliable and automated solution for efficient transportation management.

2.3. Hardware Components

2.3.1. Arduino UNO

The Arduino Uno, featuring the ATmega328P chip, is a beginner-friendly microcontroller board with ample digital and analog pins. It's widely used in robotics, IoT, and home automation projects.

2.3.2. Piezoelectric Disc

A piezoelectric disc is a device that generates electricity when subjected to mechanical stress, such as pressure or vibration. It's commonly used in sensors, buzzers, and actuators in various applications.

2.3.3. Bridge Rectifier

A bridge rectifier is an electronic component used to convert alternating current (AC) into direct current (DC). It consists of diodes arranged in a bridge configuration, allowing for full-wave rectification.

2.3.4. RFID module

An RFID module is a device that enables communication with RFID tags using radio frequency signals. It consists of an antenna and integrated circuitry for reading and sometimes writing data to tags.

2.3.5. LDR

An electronic component that varies its resistance based on the intensity of light incident upon it. LDRs are commonly used in light-sensitive devices such as streetlights, cameras, and automatic brightness control systems.

2.3.6. LED

A semiconductor light source that emits light when current flows through it. LEDs are widely used in various applications including indicators, displays, illumination, and automotive lighting due to their energy efficiency and long lifespan.

2.3.7. Jumpers

Small connectors used to electrically connect two points on a

circuit board or breadboard. They are typically short wires with a connector at each end and are used to configure or modify the behavior of electronic circuits by creating or bypassing connections.

2.3.8. Battery

A device consisting of one or more electrochemical cells that convert stored chemical energy into electrical energy. Batteries are used to power a wide range of electronic devices, from small handheld gadgets to electric vehicles, providing portable and reliable power sources.

2.3.9. Capacitor

An electronic component that stores electrical energy in an electric field. Capacitors are used in electronic circuits for various purposes such as filtering, energy storage, coupling, and timing. They come in different types and sizes, each suited for specific applications based on factors like capacitance value, voltage rating, and frequency response.

2.4. SOFTWARE SPECIFICATIONS

2.4.1. Arduino IDE

The Arduino IDE (Integrated Development Environment) is a software platform used for programming Arduino microcontroller boards. It provides a simple interface for writing, compiling, and uploading code to Arduino boards, making it accessible for beginners and advanced users alike. It supports the C and C++ programming languages and comes with a set of libraries to facilitate hardware interaction.

3. RESULTS:

The developed system effectively harnesses electricity from vibrations generated by moving vehicles through a piezoelectric sensor circuit. The prototype utilizes five piezo-disks connected in parallel, with each disk linked to a bridge rectifier. These rectifiers are then connected to a 3.3 µF capacitor, reducing DC ripple and charging a 12V battery. Power generation depends on variables such as vehicle weight, speed, and the load on the piezoelectric sensor, which converts mechanical energy into electrical power.

For example, applying 100gms of weight produces a voltage of 7-9V. Using this as a baseline, a 100kg vehicle could potentially generate 7-9KV of power, which would increase with vehicle speed. This power can efficiently illuminate street lights. Additionally, the system efficiently detects vehicles using RFID tags (Fastag cards) for automatic toll fee deduction.

Overall, the system successfully achieves its objectives and provides the desired output. It significantly contributes to energy generation and sustainable automation by employing energy conversion methods to meet power requirements and reduce vehicle carbon footprints, thus promoting a greener and more sustainable environment.

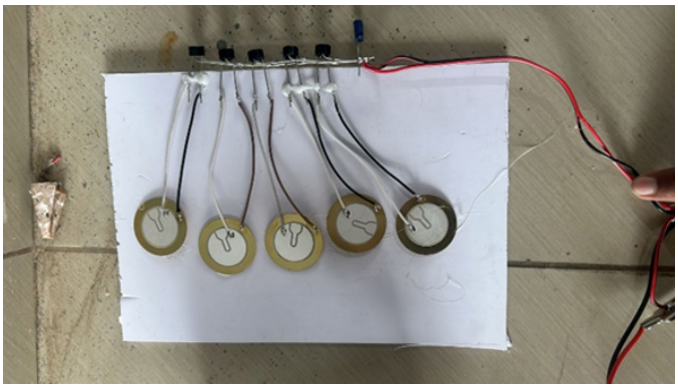

Figure 2: Power Generation Circuit

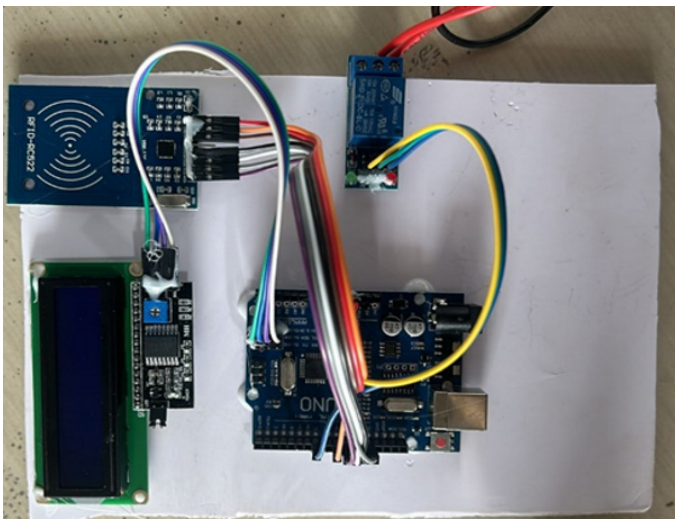

Figure 3: Toll and Streetlight Automation circuit

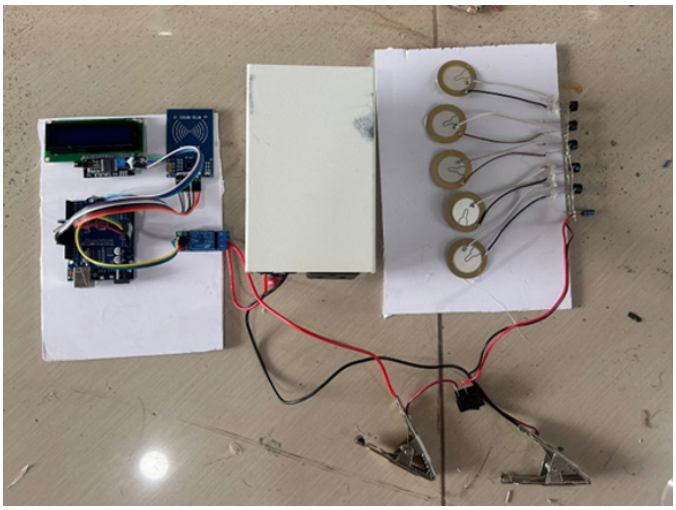

Figure 4. Overall System Prototype

4. DISCUSSION

The integrated system offers self-powered toll collection and street lighting, utilizing renewable energy from passing vehicles via piezoelectric discs. Its autonomy reduces reliance on external power sources, ensuring continuous operation. Cost-effectiveness stems from reduced grid power consumption, while environmental benefits result from lower carbon emissions. RFID technology streamlines toll collection, enhancing efficiency and reducing congestion. LED street

lights, controlled by an intelligent system, optimize energy usage based on ambient light levels. In essence, the system embodies sustainability, efficiency, and cost-effectiveness in transportation infrastructure management.

5. FUTURE WORK

Future research should explore enhancing the performance and reliability of the system through advancements in piezoelectric materials and energy harvesting techniques. Additionally, scalability considerations could involve optimizing the system's architecture for deployment in diverse geographical and traffic conditions. Integration of predictive maintenance algorithms could improve system reliability, while incorporating advanced communication protocols may enhance connectivity and data management. Furthermore, exploring the potential for integrating renewable energy sources beyond piezoelectricity, such as solar or kinetic energy, could further enhance the system's sustainability and resilience.

6. CONCLUSIONS

In conclusion, the developed system presents a promising solution for energy generation and sustainable automation. By harnessing vibrations from moving vehicles through piezoelectric technology, it efficiently converts mechanical energy into electrical power. The prototype's ability to produce significant voltage levels even with moderate vehicle weights indicates its potential for widespread application, particularly in street lighting systems. Moreover, its integration with RFID technology for automatic toll fee deduction showcases its versatility and adaptability to modern transportation infrastructure. Overall, this innovative system not only meets its objectives but also contributes to a greener and more sustainable environment by reducing carbon emissions and promoting energy efficiency.

7. REFERENCES

1. Asokan V, Indhumathi G, Sowmiyasri A, Sumayyah S, Vidhyasri S, "RSSI Based Smart Tollgate Billing System", (2023) 9th International Conference on Smart Structures and Systems (ICSSS).
2. Ahmed Tamim Zabir Prince, Dipta Paul, Zahid Hasan Khoka, Md. Samannur Hasan, Arshad Uddin Afnan, Asif Ahmed, "Smart Prepaid Toll Management System Using RFID" (2023) 7th International Conference on Computing, Communication, Control and Automation (ICCUBEA).
3. Moaiad Ahmad Khder, Kareem Abbas Dawood, Rozin Badeel Abdal, Sarah Abdulrahman Alqaisy "Automated Road Toll Collection and Vehicle Tracking (ARTCVT) Using Advanced RFID and GSM Technology" 2022 SU International Conference in Emerging Technologies for Sustainability and Intelligent Systems (ICETSIS).
4. Bhuvanesh M, Gokul S, Manirathinam M, Dr. M.V. Molykutty, Dr. G. Puthilibai, "PIEZOELECTRIC PAVEMENT" (2020) International Conference on Power, Energy, Control and Transmission Systems (ICPECTS).
5. T. Prathyusha, B.Sridhar, T. Jagadeesh, Y.Swarna Deepika "Design an IOT Based Highway Toll Plaza System" 2023 IEEE International Student's Conference on Electrical, Electronics and Computer Science.
6. Sajal Sahu, Virendara Kumar Verma, Giriraj Yadav, Suresh Kumar Gawre, Riya Arya, Agnoor Hema, Ritu Verma, "Piezoelectric Based Power Generation for Portable Charging System" (2023) IEEE International Students' Conference on Electrical, Electronics and Computer Science.
7. Vikas D. Patil, Ranjeet R. Suryawanshi, Vinay S. Mandlik, Ramchandra K. Gurav "Micro-Generator Based Power Harvesting Tiles" 2022 International Conference on Recent Trends in Microelectronics, Automation, Computing and Communications Systems (ICMACC).
8. Ramanamma P, M. Jayanthi, Anuj M A, A. Dharmik Sai Reddy, Devu Maheswar Reddy, G. Pavan Kalyan Reddy, "Footsteps Based Sustainable Energy Generation and Consumption System", Proceedings of the Third International Conference on Artificial Intelligence and Smart Energy (ICAIS 2023)
9. Dr.P.Hema Chandu, A.Venkata Vinay, K.N.D. Jagadeesh, S. S. V. Kanaka Raju, V.G.Mani Sharan, "Footstep Micro-Level Power Generation", (2022) 3rd International Conference on Communication, Computing and Industry 4.0 (C2I4).
10. Logeshwaran M, J.Joselin Jeya Sheela M.E., (Ph.D.), Parvathi Priya A M.Sc., M.Phil.,(Ph.D.) "A High-Efficiency Power Generator by Footsteps Using Piezoelectric Effect" Proceedings of the Second International Conference on Artificial Intelligence and Smart Energy (ICAIS-2022) IEEE Xplore Part Number: CFP22OABART; ISBN: 978-1-6654-0052-7.